Overview of Available Quantitative LTMO Methods

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Overview

- Process
- Requirements & Expectations
- Available Tools
- Emerging Approaches
- Application

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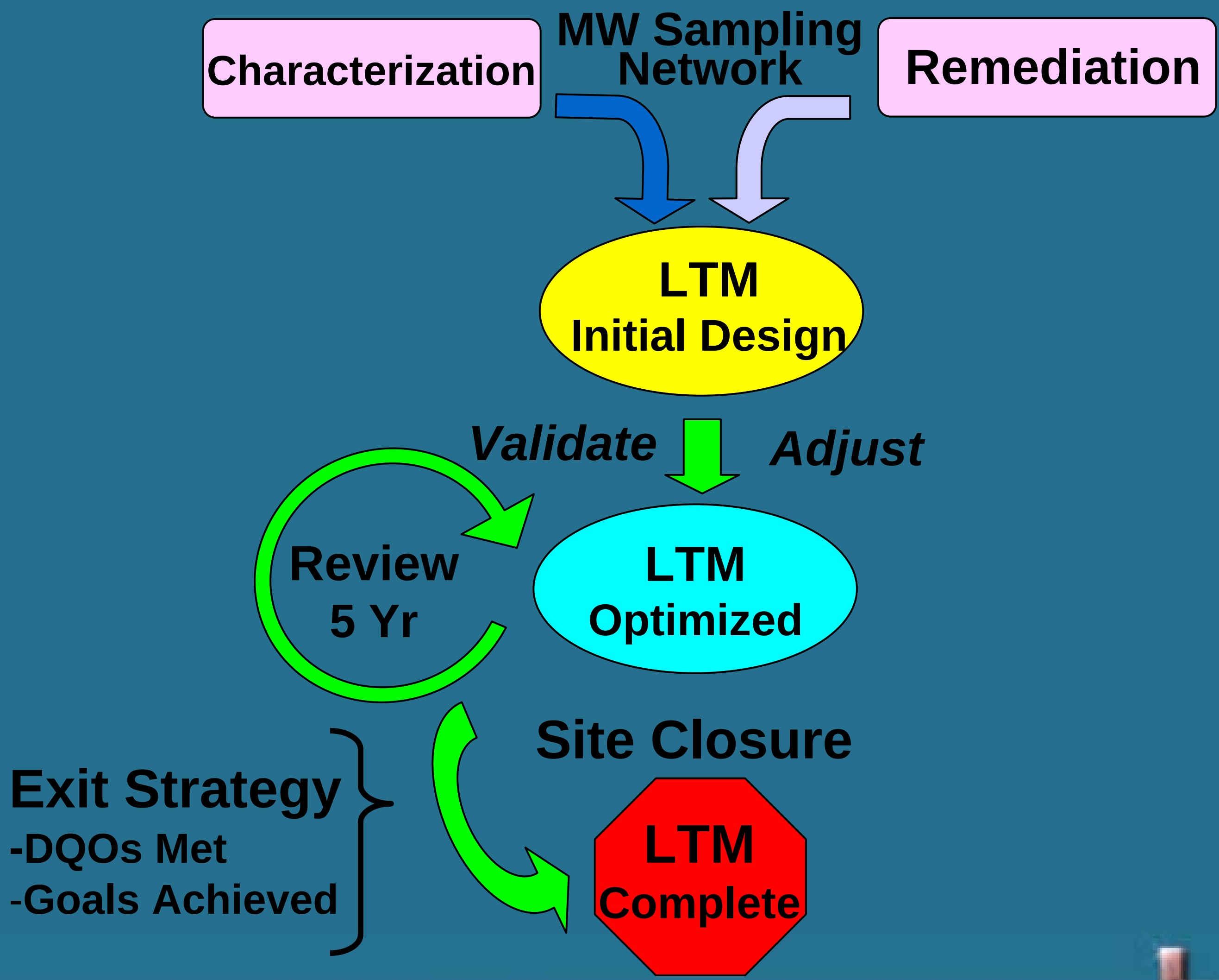
What is the Opportunity?

- LTMO case studies demonstrate redundancy in well networks
- Typical LTM sampling effort can be reduced by 20% – 40%
- LTMO focuses on essential data and accepts tolerable uncertainty in environmental decision-making
- Helps to improve & simplify LTM programs

LTMO Tools
What Do They Do?

- Identify essential sampling locations
- Determine an optimal sampling frequency
- Assess relative importance of individual wells
- But, there is *no purely objective* solution or answer

LTMO "Big Picture" Roadmap to Site Closure



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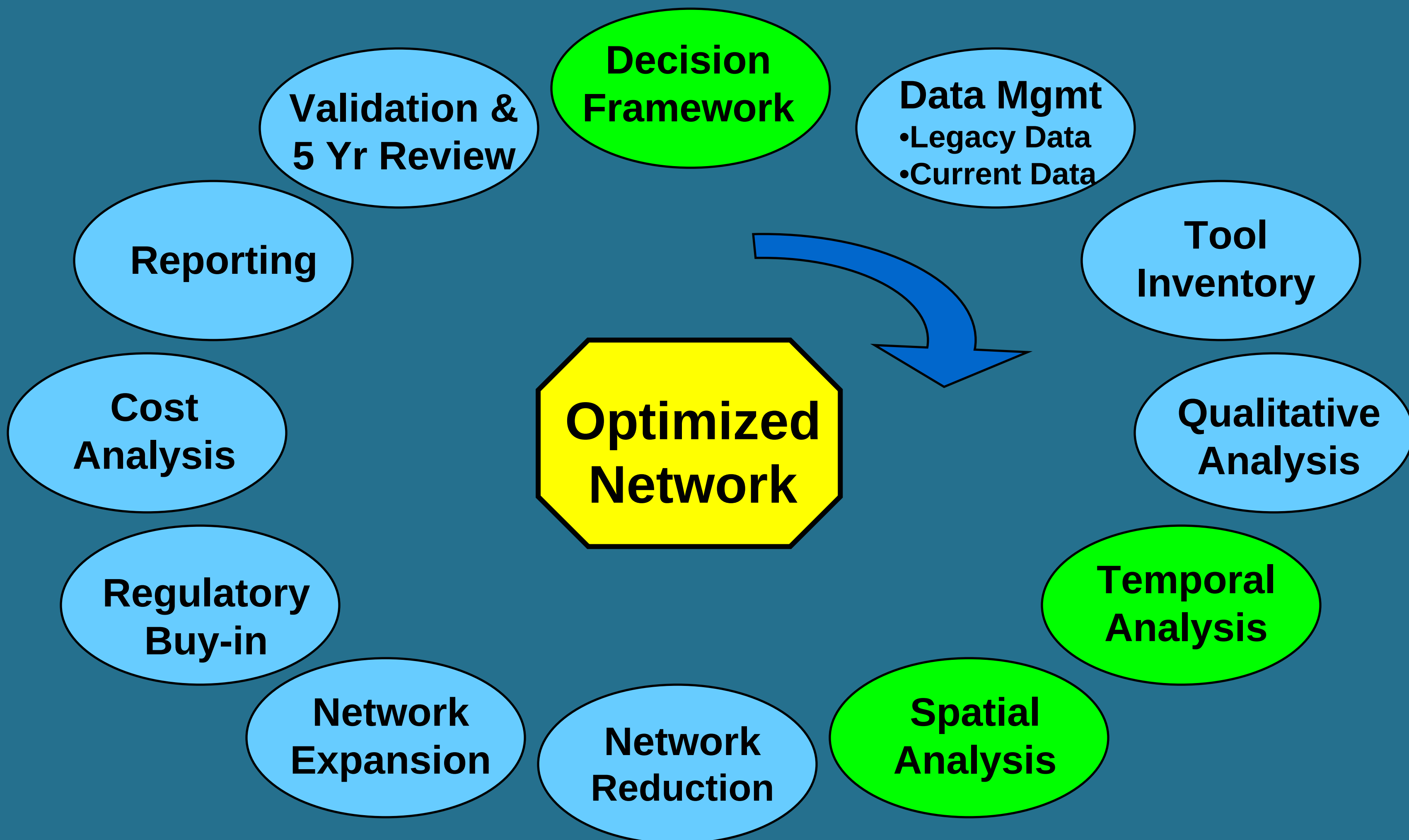
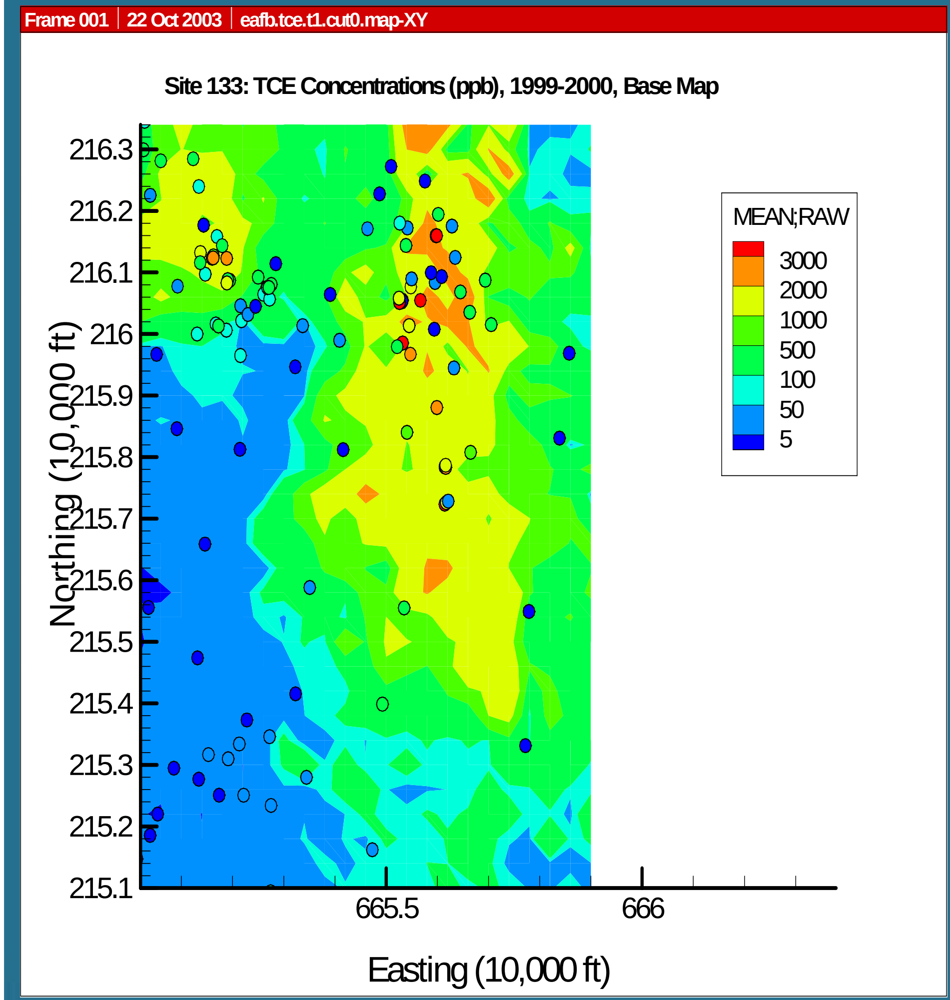
LTMO Major Components General Process

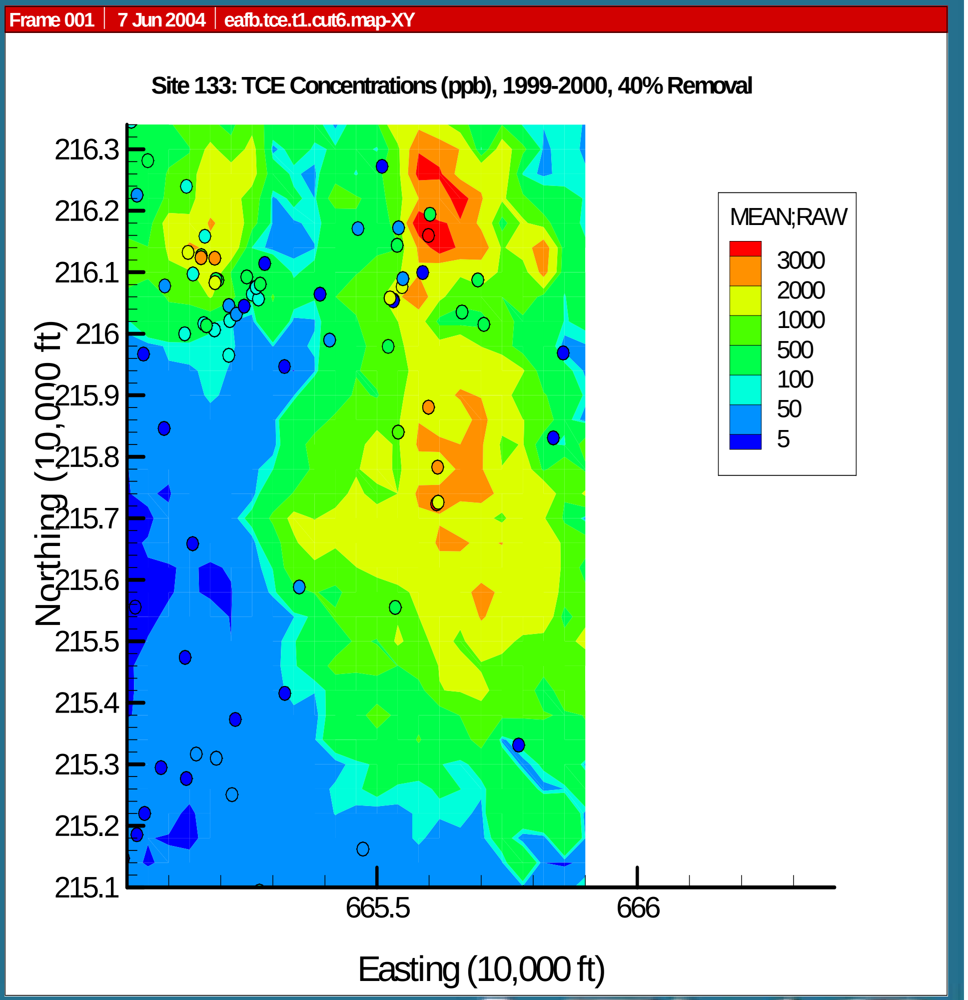


LTMO Involves Spatial Comparisons

All Wells



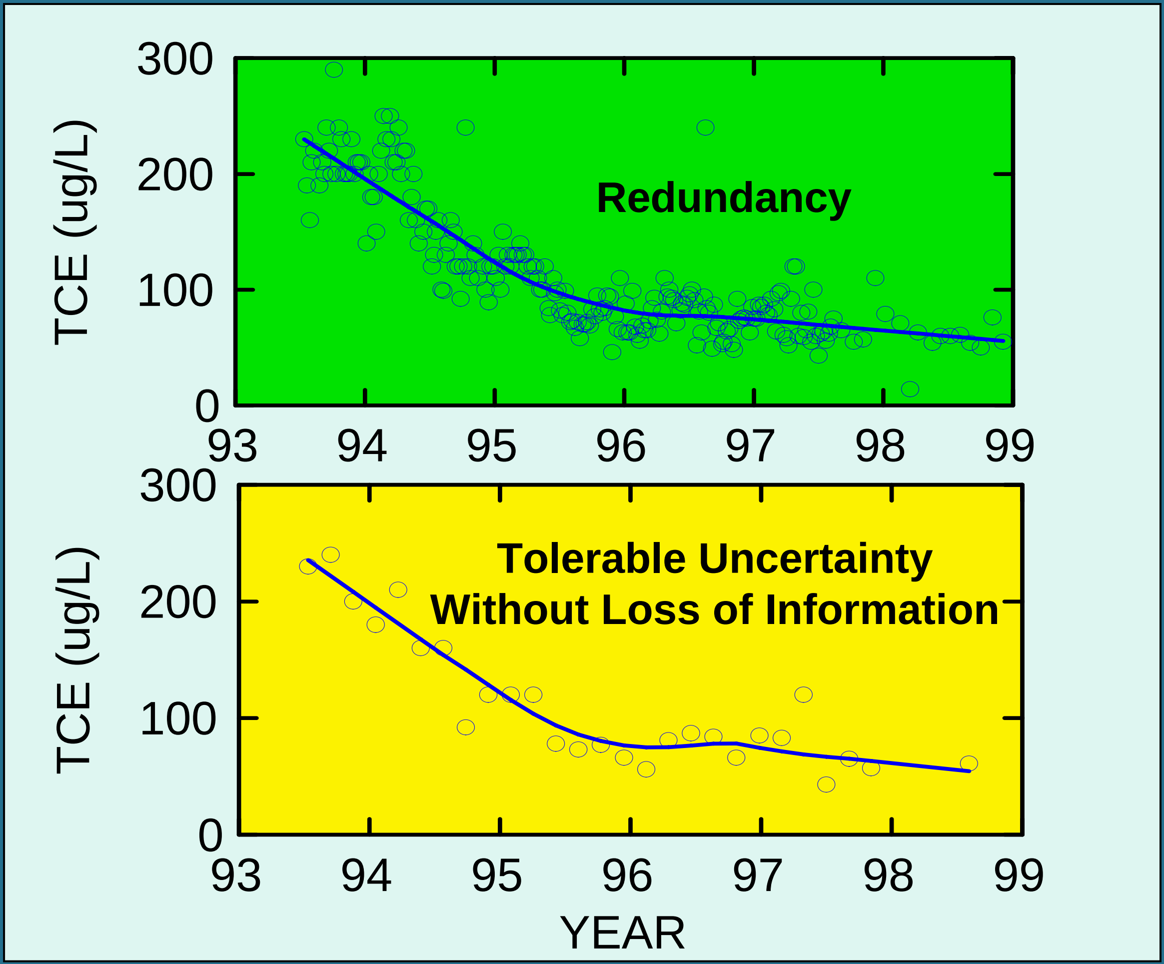
Well Reduction 40%



LTMO Involves Temporal Comparisons

"Nice to have"
All Data
Samples = 240

"Essential"
90% Reduction
Samples = 27



Requirements

- Electronic data
- Conceptual site model
- Data sufficiency; sample size, # events
- Description of current monitoring program
- Well construction & coordinates
- Cleanup goals & regulatory limits

What's Out There?

PARSONS

3-Tiered LTMO

MAROS Decision Support System
for Optimizing LTM Programs

LONG-TERM MONITORING OPTIMIZATION GUIDE

FINAL
Version 1.1

October 1997

INTERIM FINAL

Guide to Optimal Groundwater Monitoring

Prepared for:
Naval Facilities Engineering Service Center
Port Hueneme, California

Remediation Optimization

Federal Remediation Technologies Roundtable

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Data Quality Objectives and Long-Term Monitoring Guidance

Navy and Marine Corps Working Group

Optimizing Remedial Action Operations and Long Term Monitoring

Long-Term Monitoring (COMING SOON!!)

Cost-Effective Sampling (Subterranean Research,

Geostatistical Temporal/Spatial (GTS) Optimization Algorithm

Long-Term Groundwater Monitoring: The State of the Art

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AFCEE Optimization Tools

- **Optimization Tools**
  - **Algorithm**
    - **GTS**
  - **Software**
    - **MAROS**

Geostatistical Temporal-Spatial (GTS) Algorithm

- Design emphasizes decision-logic framework
- “Plug-in” architecture
- Uses geostatistical and trend optimization methods that are semi-objective
  - Variogram = spatial correlation measure
  - Kriging = spatial interpolation = spatial regression
  - Locally-Weighted Quadratic Regression (LWQR)
- Software now available

GTS Temporal Analysis

- Flexible strategies for optimizing sampling frequencies
  - Individual well analysis; “iterative thinning”
  - Temporal variogram for well groups & broad areas

Iterative Thinning

- Individual well analysis
  - Estimate baseline trend
  - Randomly “weed out” data points
  - Re-estimate trend
  - Assess significant departure from baseline

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Iterative Thinning Requirements

- At least 8 sampling events per well
- NDs set to common imputed value
- Complex trends, seasonal patterns OK
  - LWQR fits non-linear trends

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GTS Spatial Analysis

- Locally weighted quadratic regression (LWQR) replaces Kriging algorithm
- LWQR Benefits
  – Smoothing technique, not an interpolator
  – Robust; does not assume or require a spatial covariance model (variogram)
  – Can estimate complex seasonal trends and nonlinear data
  – Handles multiple values in time and space
  – A less complex and flexible alternative for software development

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GTS Spatial Analysis Requirements

- At least 20-30 regularly-monitored wells
  - Irregular sampling schedules OK
- Best COCs have:
  - Higher detection frequencies
  - Greater spatial spread & intensity
- Good to have 2-3 years of most recent monitoring data at each well

What is MAROS?

Monitoring and Remediation Optimization Software

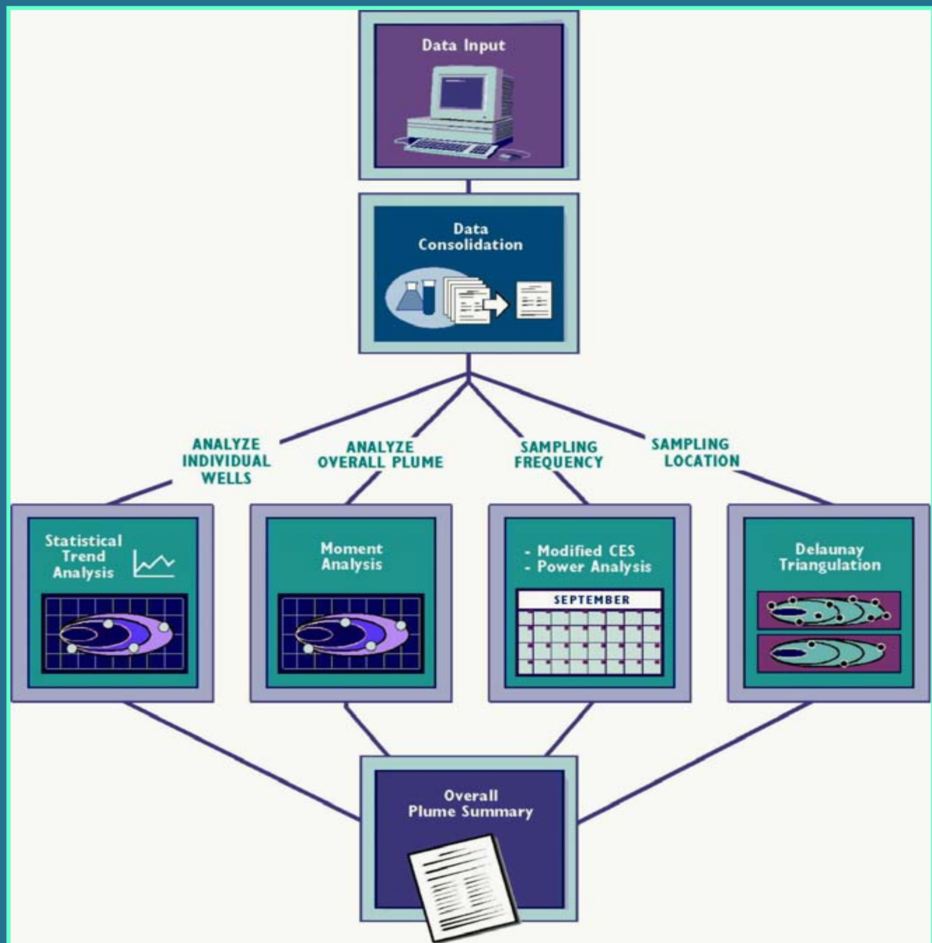
- **MS Access Database application** → ***YES***

  - Simple statistical and heuristic tools
  - Not mathematical optimization
  - Modular
  - Simple database input
  - Employed after site characterization and remediation activities are largely complete

Limitations of MAROS

- Site modeled as a single plume
- Two-dimensional analysis
  - Different units analyzed separately
  - Multiple sources analyzed separately
- Simplifies and consolidates data
- Does not evaluate plume outside of current network
- Does not include purely regulatory requirements

MAROS Modules



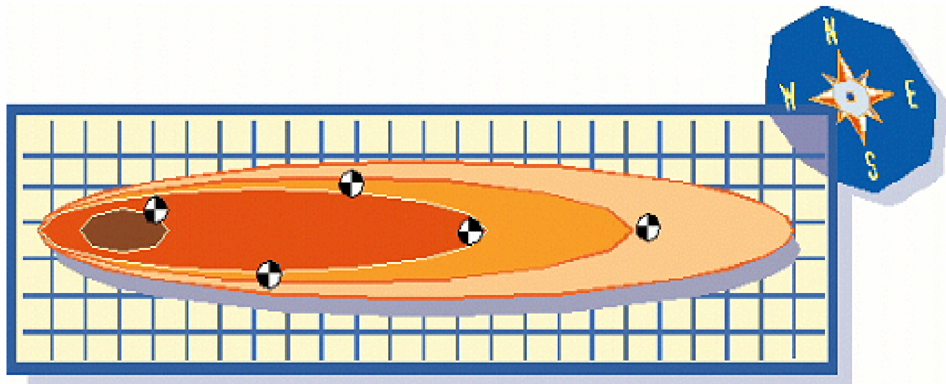
- Database Input:
- Automated Data Consolidation
- Optimization Tools:
  - *Plume Trend Analysis*
  - *Moment Analysis*
  - *Well Redundancy*
  - *Well Sufficiency*
  - *Sample Frequency*
  - *Data Sufficiency*

Data Input & Data Reduction

Monitoring and Remediation Optimization System (MAROS)

SITE DETAILS

Well Coordinates



Enter the coordinates for the wells that are missing data. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Well	Source/ Tail	X Coordinate (ft)	Y Coordinate (ft)
MW-1	S	13	-20
MW-12	S	100	-8
MW-13	S	65	23
MW-14	S	102	20
MW-15	S	190	-125
MW-2	T	-2	30
MW-3	T	35	10

<< Back | Next >> | Help | Well Map

Well Network Input Data:

- Source Wells (DNAPL)
- Tail Wells
- Extraction Wells

Data Consolidation:

- Non-detect values set to minimum or 1/2 detection limit.
- Average Duplicates
- Trace Values set to actual values
- Time Consolidation

Plume Characterization

- Characterization of the plume is complete—
  - Seasonality known
  - Hydrology is known
  - Significant COCs known
  - Source areas known
- MAROS reveals broad trends—so individual data points are less significant

MAROS Uses Delaunay Method

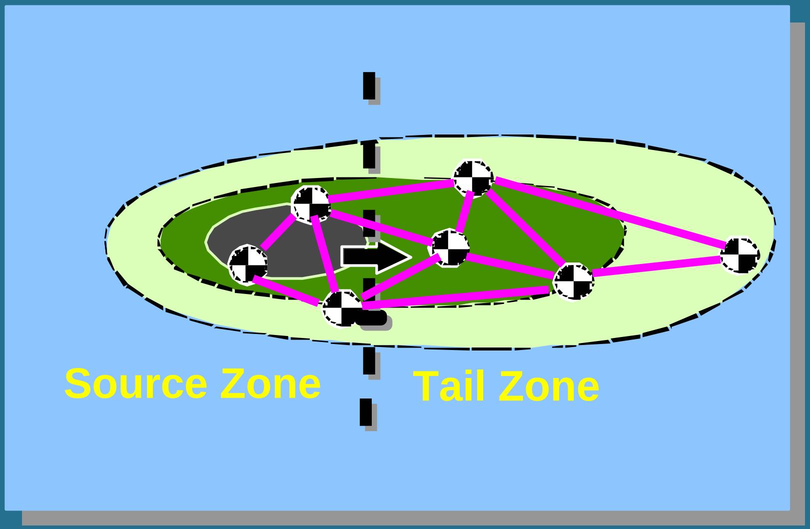
Well Redundancy and Sufficiency Analysis

Delaunay Method:

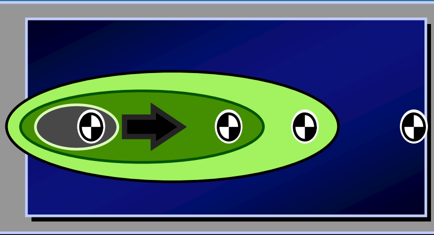
- **Eliminate "redundant" wells**

  OR

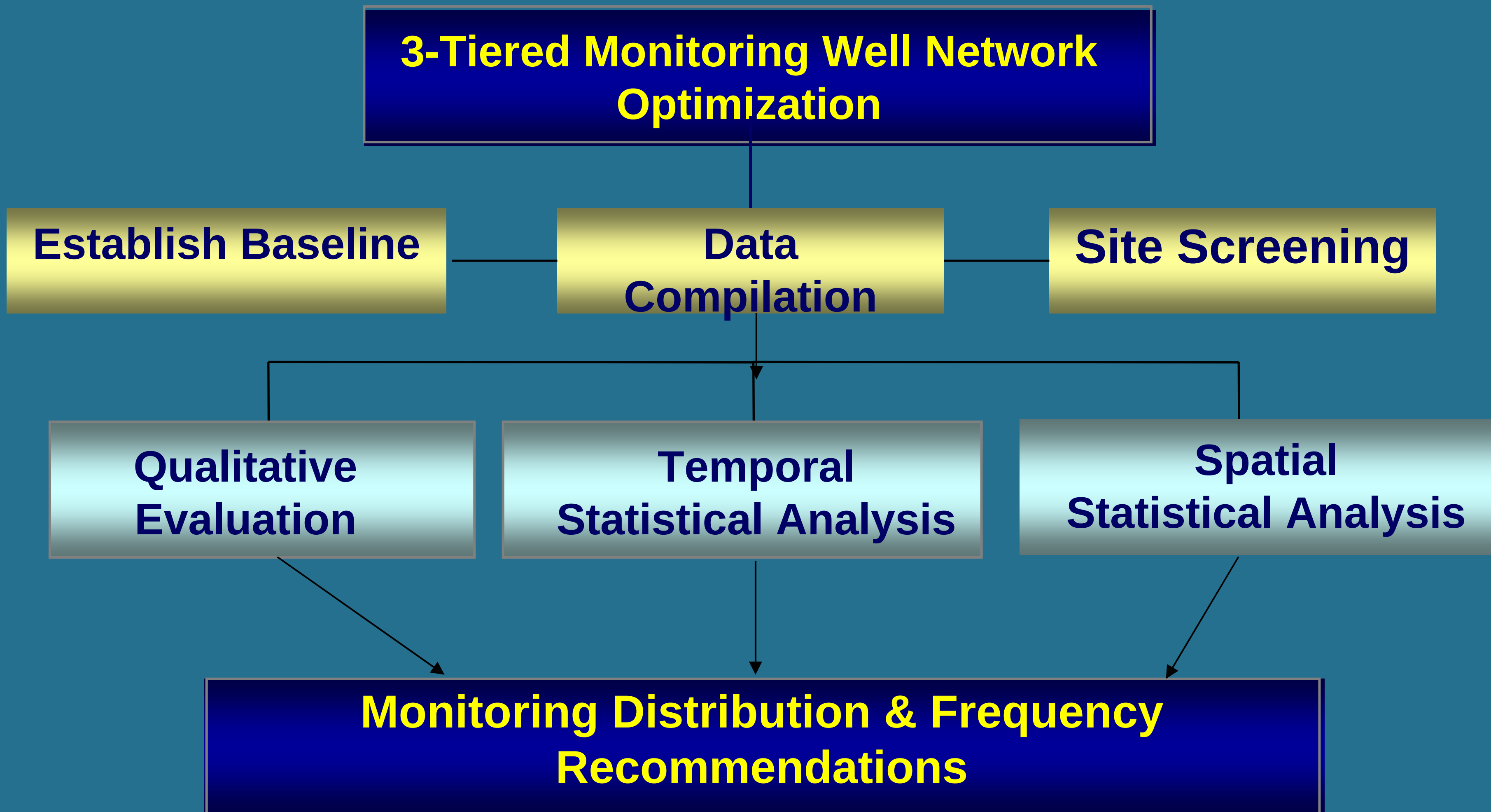
- **Add wells in areas with high concentration uncertainty.**



KEY POINT: **Does estimated concentration change if well is removed?**



Parsons' 3-Tiered LTMO At A Glance



3-Tiered LTMO Strategy

- Qualitative Evaluation
  - Experienced geologist big-picture analysis
- Temporal Statistical Evaluation
  - Mann Kendall trend analysis
- Spatial Statistical Evaluation
  - Geostatisical Kriging relative predicted error analysis

3-Tiered LTMO Analysis

Combines three evaluations to optimize the distribution and frequency of groundwater sampling.

3-Tiered Approach Qualitative Evaluation

- DATA
  - Site characterization
  - Monitoring results
  - Monitoring Network DQOs, etc.
- INFORMATION
  - Value of each well in big picture context
- SOLUTION
  - Recommend:
    - Well retention or removal
    - Optimal sampling frequency

Requires Experienced Hydrogeologist Familiar With Site

3-Tiered Approach Temporal Evaluation

- DATA:
  - >4 sampling results over time
  - Well/plume location & GW direction
  - Concentration relative to MDLs and PQLs
- INFORMATION:
  - Mann-Kendall Trend analysis
  - Automated process (MAROS/GIS script)
- SOLUTION:
  - Recommend retention or removal/reduction based on decision rationale

3-Tiered Approach
Spatial Evaluation

- DATA
  - Spatial "Snapshot" of Plume
    - Most recent chemical concentrations
    - Indicator chemical
    - Wells in same zone
- INFORMATION
  - Geostatistical (Kriging) Evaluation
    - Develop spatial model (semivariogram)
    - Calculate Kriging predicted standard error metric for each well
  - Conducted Using ArcGIS Geostatistical Analyst Extension
- SOLUTION
  - Recommend removal or retention based on relative value of spatial information of each well

Requires Experience with Geostatistics & Semivariogram Development

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Emerging “Next Generation” Methods LTMO

- Mathematical optimization
- Machine learning
- Integrated algorithms
- Most field-scale applications have used:
  - Genetic algorithms
  - Simulated annealing
  - Tabu search

Mathematical Optimization

- Uses a computer to automatically search for the best solution to a problem that you specify
  - e.g., finding redundant monitoring locations or times
- Useful tool when many possible solutions exist and it's too time-consuming to examine all of them

Machine Learning

- Machine learning models include
  - Analytical models, such as neural networks
  - Geostatistical or numerical models coupled with analytical models to capture errors
- Process for monitoring
  - Use historical data to fit a trend model
  - When new data are obtained
    - Compare actual trend with predicted trend and provide alerts of significant deviations
    - Identify locations/times where additional data would be most beneficial to reducing risks

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Adaptive Environmental Monitoring System (AEMS)

- Under development at RiverGlass Inc., Champaign, IL
  - Software development company launched by the University of Illinois
  - Project lead: Barbara Minsker, PhD (minskerconsulting@insightbb.com)
- Beta testing of AEMS expected to begin in late Summer 2005
- Only software that includes state-of-the-art machine learning and mathematical optimization technologies, as well as standard statistical & geostatistical approaches

Information Content Fused Approach

- Integrated algorithm(s) consist of:
  - Simulation models based on physics
  - Data models based on sampling
  - Uncertainty handled through geostatistics
- Information content fusion (Data & Physics):
  - Signal processing (i.e. Kalman Filters, etc.)
  - Genetic Programming
- Optimal System Estimate
  - Optimal estimate of “system” for locating plume at given time, or time-space correlated estimates of long term monitoring programs

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Emerging Methods Summary

- Emerging technologies offer great promise
- Power, adaptability of genetic algorithms and other methods cannot be denied
- Will play more important role as computer performance & costs improve

LTMO Tool Selection Factors

- Site conditions & existing network
  - Scale of network; no. of wells & sampling events
  - Single vs Multiple sites
  - 2D vs 3D analysis
  - Single vs Multiple aquifers
- Choice of spatial & temporal algorithms
- Human resources & available technical expertise
- Regulatory input & concurrence

Summary

- A variety of LTMO tools are available
- Many factors determine choice of tools for specific application
- Next generation methods offer much promise
- Multiple LTMO tools may be used over time at any given site
- Improving LTM programs & supporting environmental decisions are key goals

Thanks

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